SuperNova / Acceleration Probe (SNAP)

An Experiment to Measure the Properties of the Dark Energy of the Universe

The Institutions of the SNAP Collaboration

Lawrence Berkeley National Laboratory
Space Sciences Laboratory
CNRS-IN2P3, LPNHE, and College de France
University of Maryland, College Park
University of California, Berkeley
University of Chicago
Space Telescope Sciences Institute
California Institute of Technology
Gemini Observatory
European Southern Observatory
University of Stockholm
University of Lisbon

November 24, 1999

Agenda	East Coast	West Coast
Executive Session	8:30	5:30
Perlmutter - Overview, Supernova Science Observation Strategy 50 min + 15 min questions	9:00	6:00
Turner - Omega, Lambda, w, Q 30 min + 5 min questions	10:05	7:05
Break - 10 min.		
Smoot - CMB (by phone) 10 min.	10:50	7:50
Aldering - Systematics, Calibration, Data Package, Comparisons 35 min + 10 min questions	11:00	8:00
Levi - Instrumentation, Optics, Imager, Technology, R&D, Cost, Schedule 30 min + 10 min questions	11:45	8:45
Lunch - 35 min.	12:25	9:25
Harvey - SSL/LOI 15 min	1:00	10:00
Heetderks - Spacecraft, Mission Ops. 10 min	1:15	10:15
Perlmutter - Wrapup 10 min	1:25	10:25
Executive Session 90 min	1:35	10:35

Outline

1. Measuring cosmological parameters with SNe: current results and new puzzles.

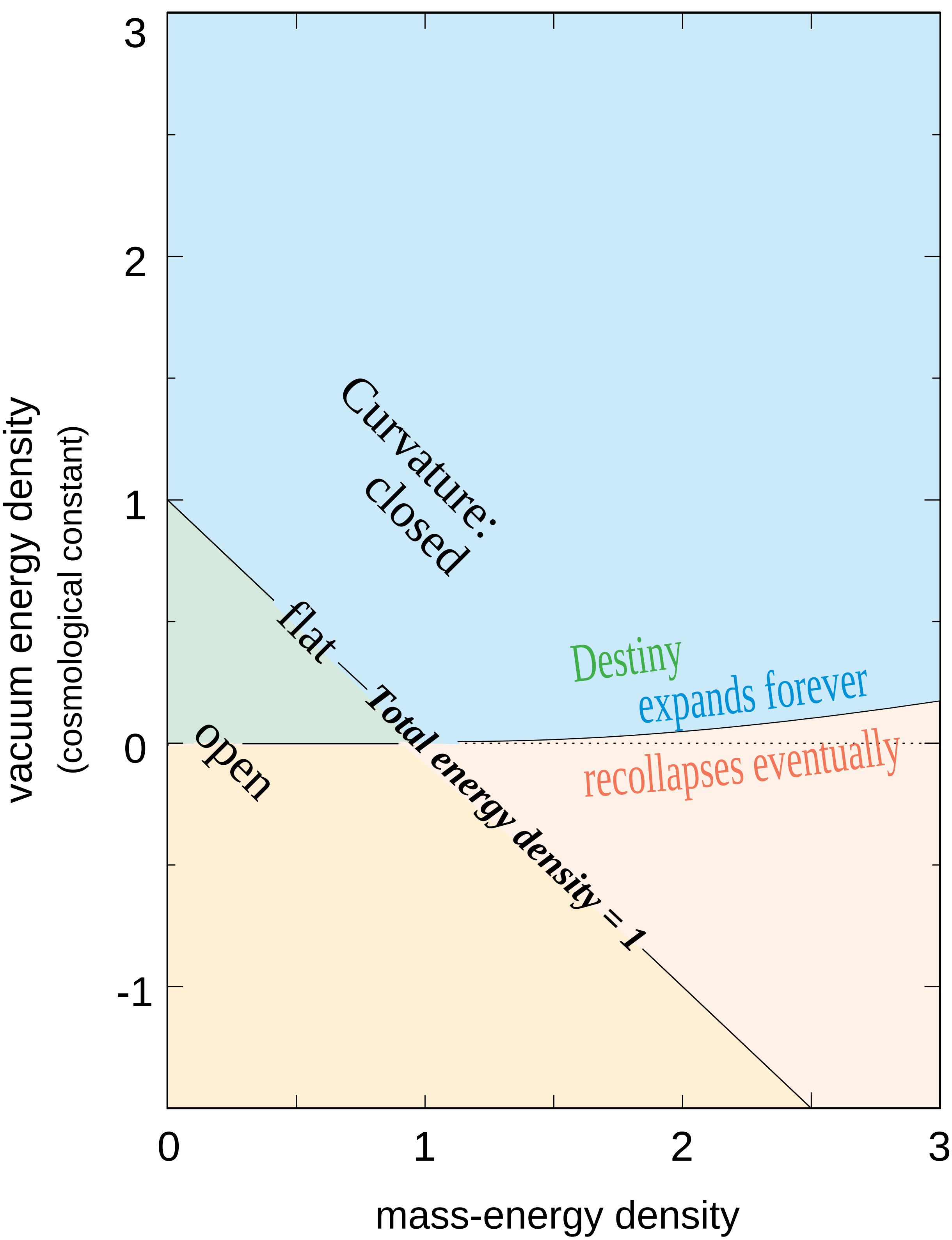
2. How can we address these puzzles?

3. Inadequacy of ground-based or space-based alternatives.

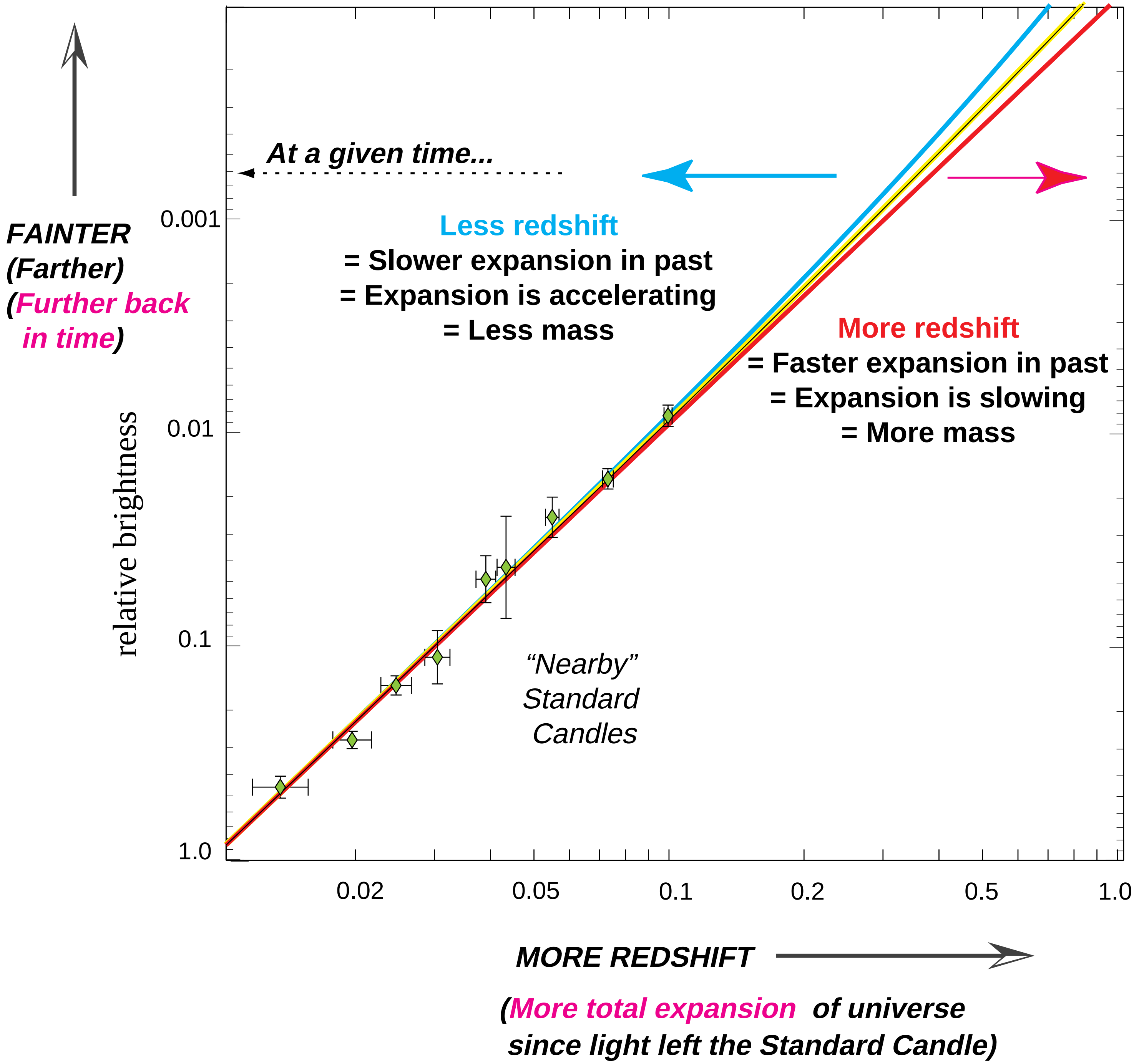
Fundamental Questions:

- *Will the universe last forever?*
- *Is the universe infinite?*
- *What is the universe made of?*

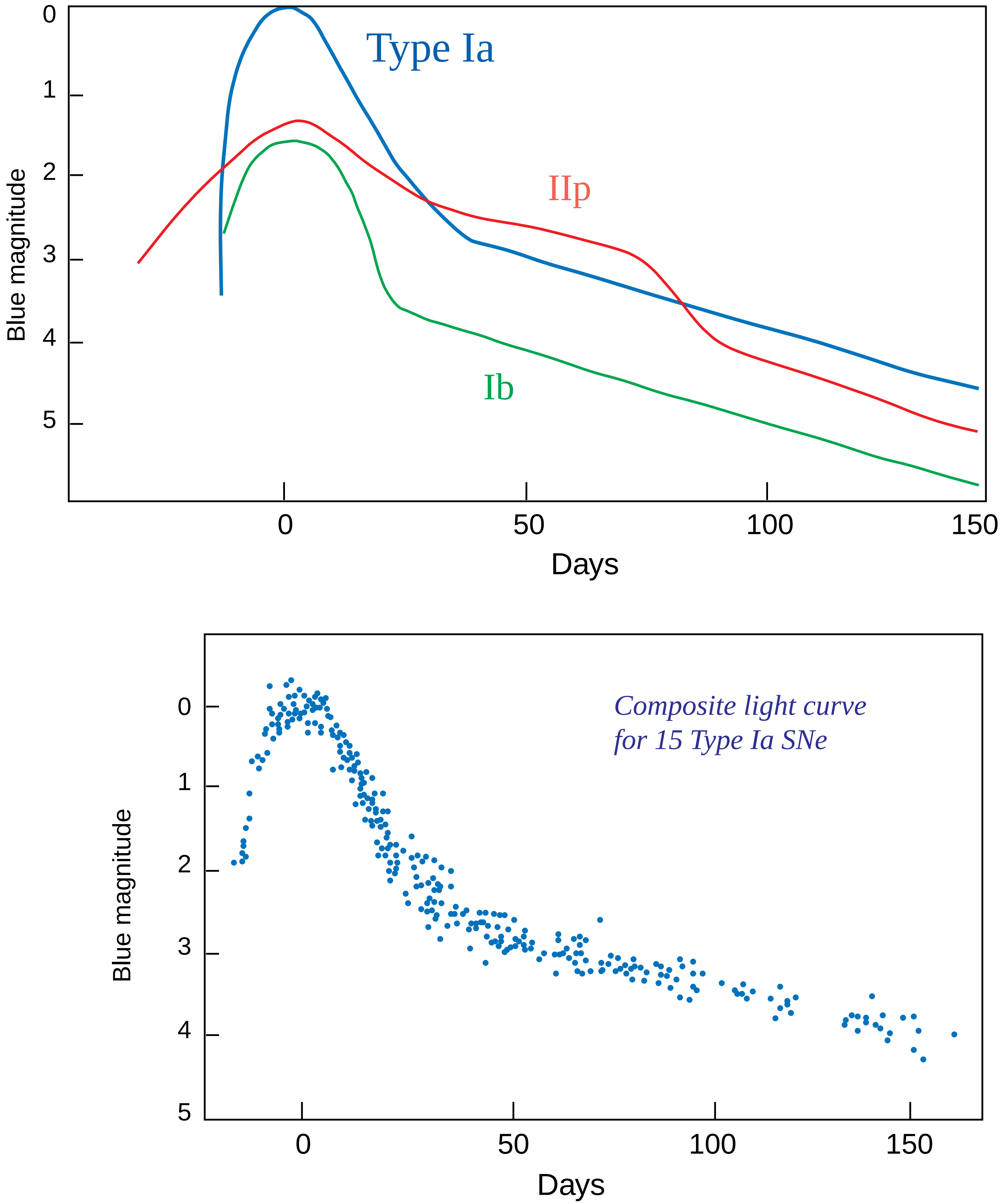
The Geometry and Destiny of the Universe

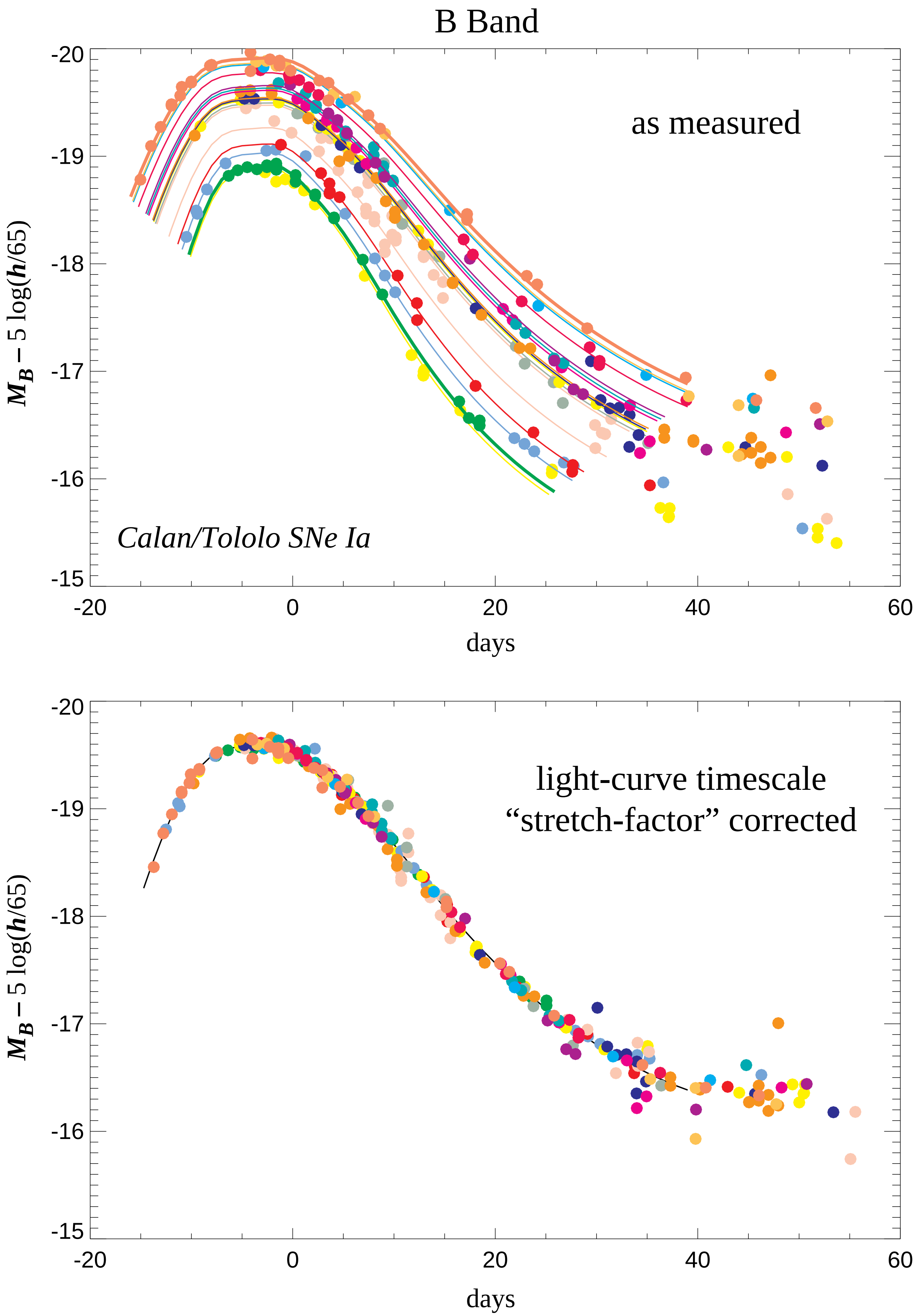


The Hubble Plot: A history of the "size" of the Universe



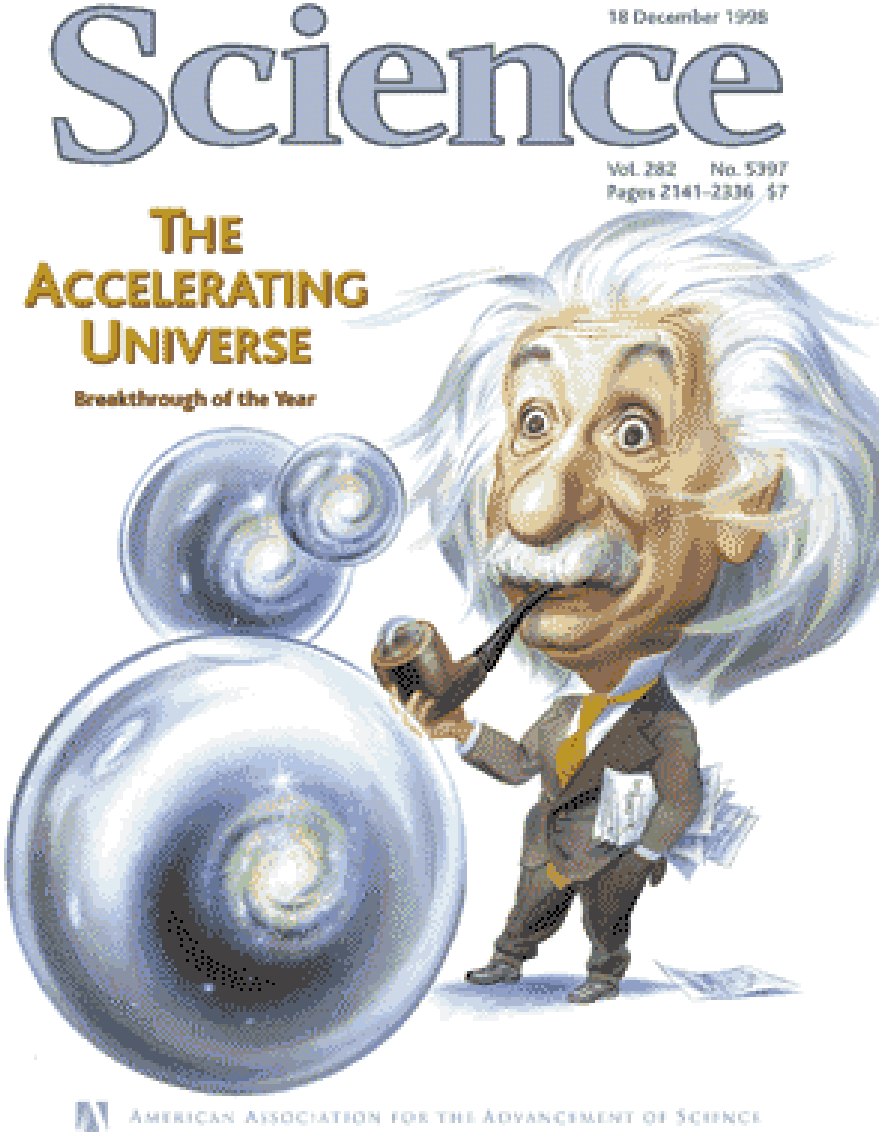
Supernova Light Curves

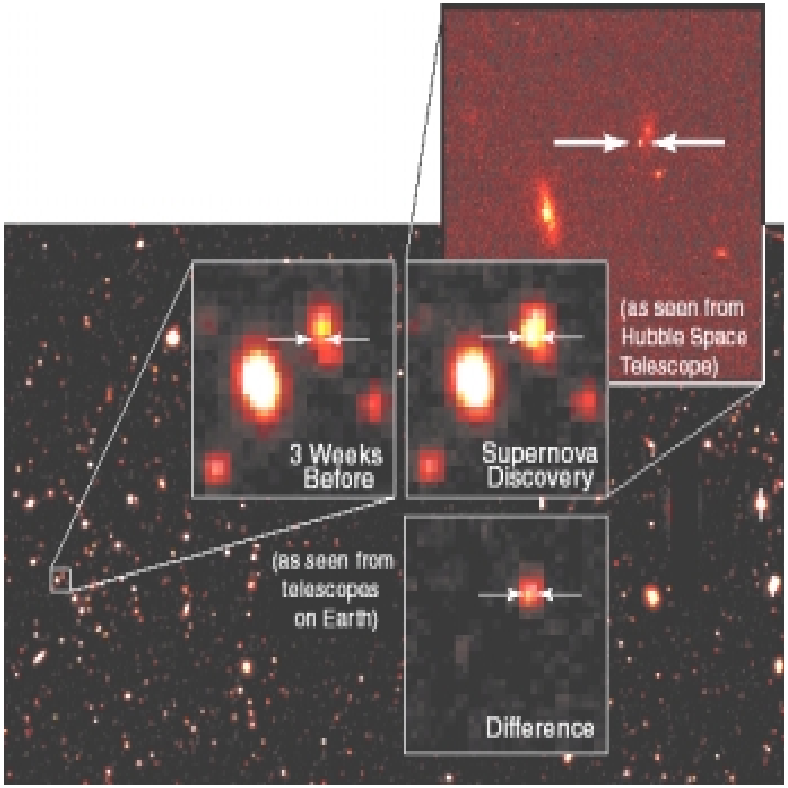




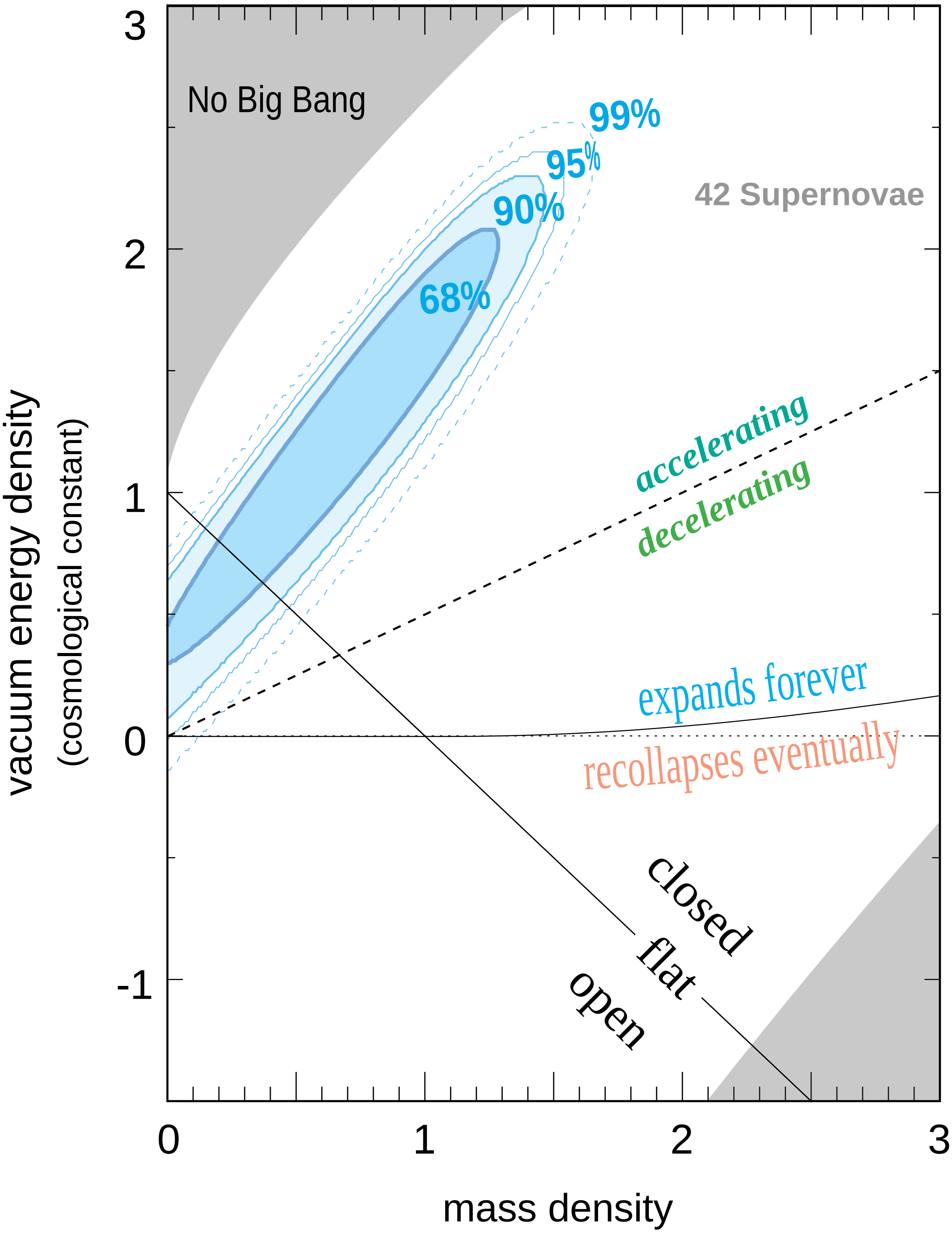
Kim, *et al.* (1997)

Astrophysics to Understand the Universe
Mass Density, Vacuum Energy Density, and Curvature



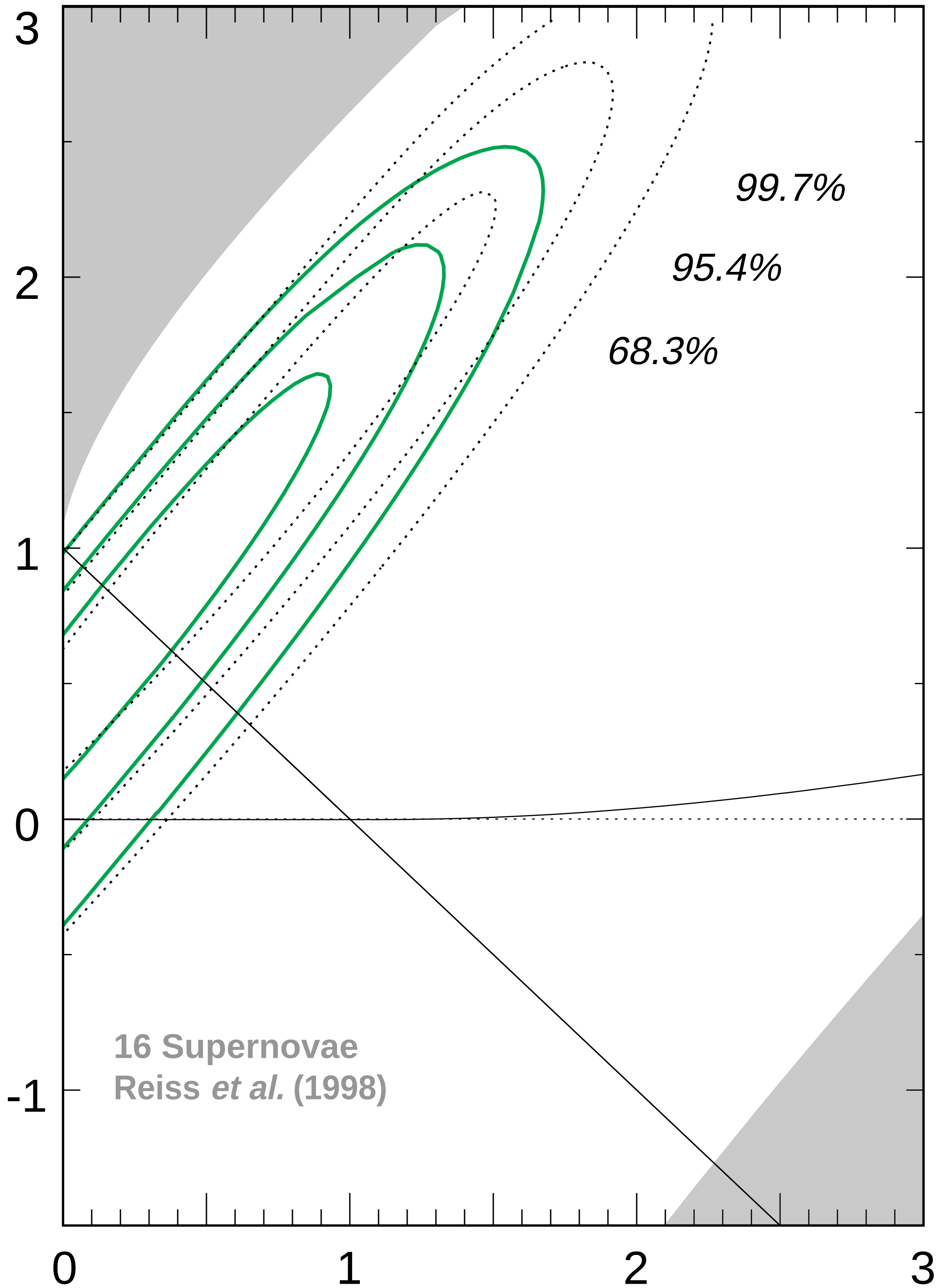


Supernova results confirming earlier hints that there is an accelerating energy.



Supernova Cosmology Project
Perlmutter *et al.* (1998)

Ap.J.
astro-ph/9812133



3
2
1
0
-1
0
1
2
3
99.7%
95.4%
68.3%
16 Supernovae
Reiss *et al.* (1998)

The implications of an accelerating universe:

1. The expansion is not slowing to a halt and then collapsing (i.e., the universe is *not* "coming to an end"). In the simplest models, it will expand forever.

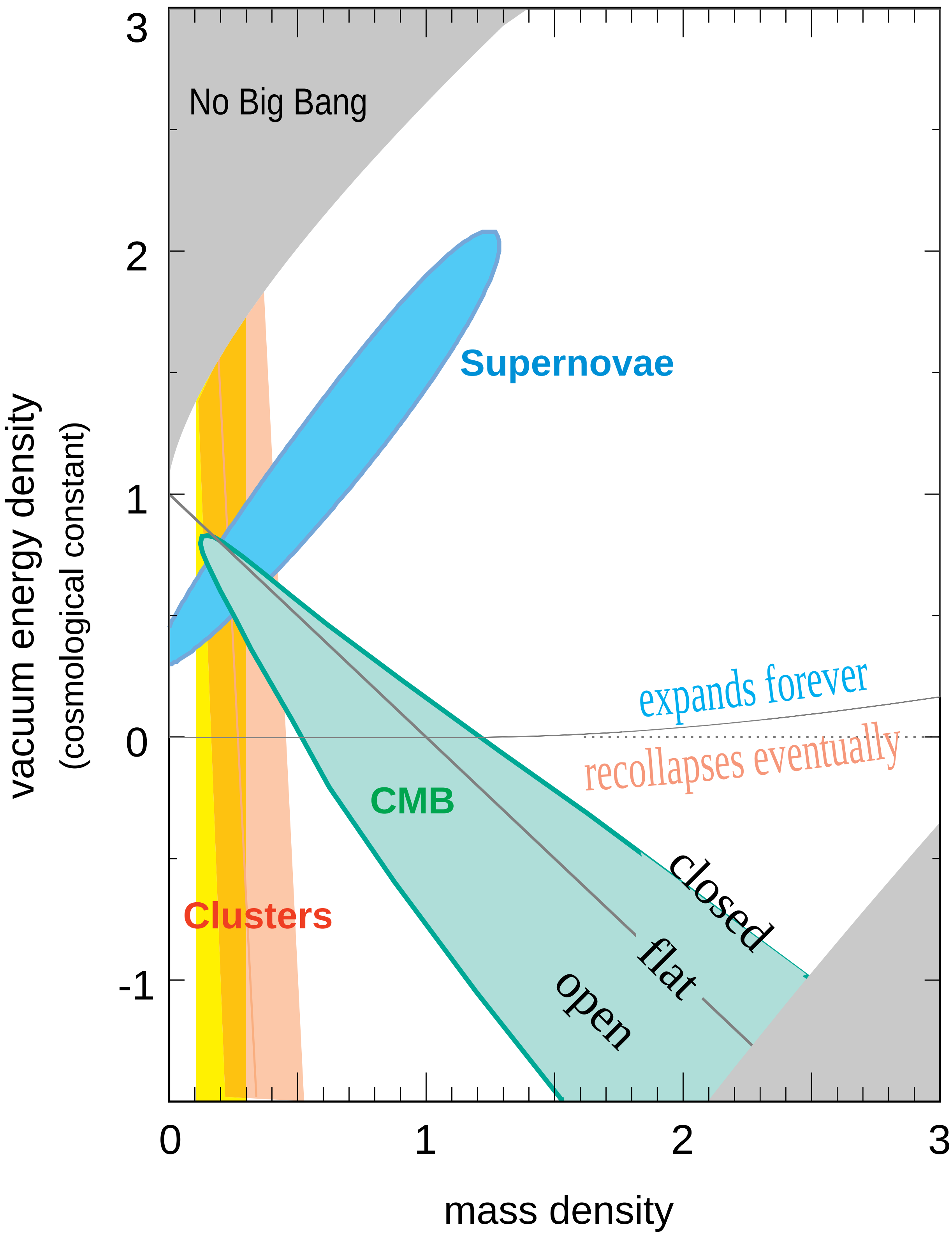
2. There is a previously unseen energy pervading all of space that accelerates the universe's expansion.

   This new accelerating energy ("dark energy") has a larger energy density than the mass density of the universe (or else the universe's expansion wouldn't be accelerating).

What we don't know is:

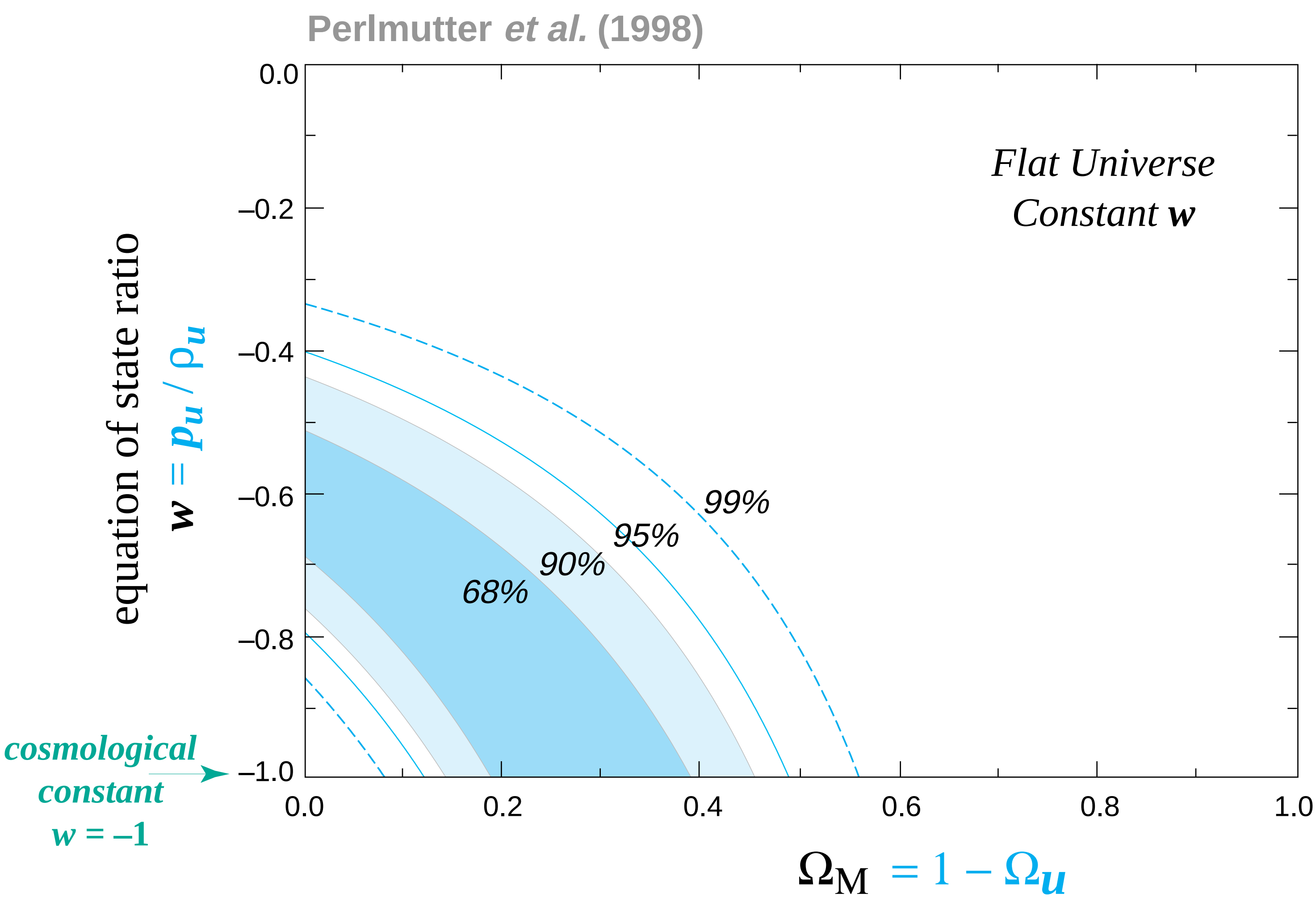
1. How much of mass density and dark energy density is there? I.e., how much dark matter and dark energy do we need to look for?
   The answer to this question determines the "curvature" of the universe, and can tell us about the extent of the universe: infinite or finite.

2. What is the "dark energy"? Particle physics theory proposes a number of alternatives, each with different properties that we can measure. Each of the alternative theories raises some important questions/problems of fundamental physics.



No Big Bang
Supernovae
expands forever
recollapses eventually
CMB
closed
flat
open
Clusters
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3

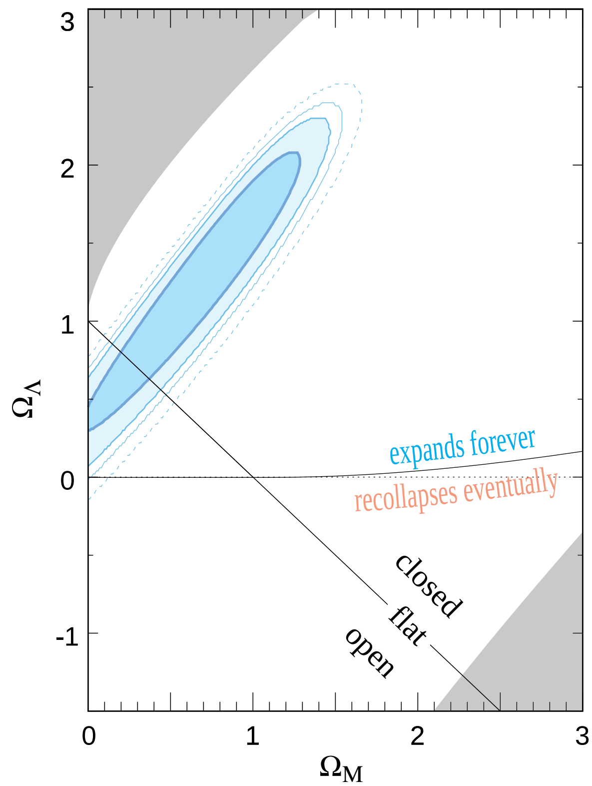
Unknown Component, Ω_u, of Energy Density



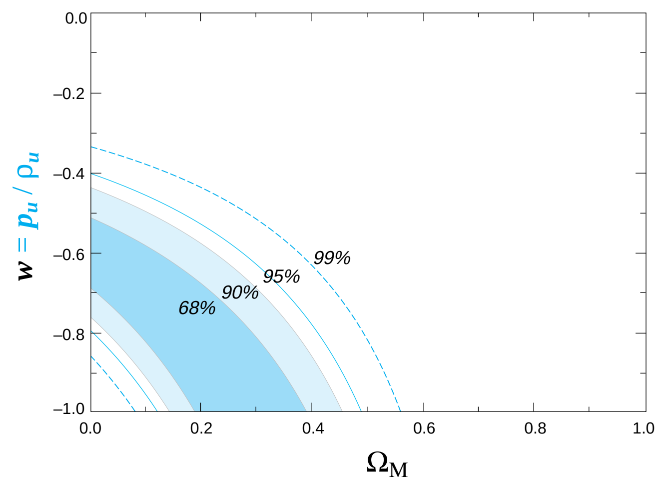
c.f. Garnavich et al. (1998)

How can we address these new questions?

Greatly improve:



and:



...And look for details of w(z).

It is necessary but NOT sufficient to find and study

- more SNe Ia
- farther SNe Ia

because the statistical uncertainty is already
within a factor of two of the systematic uncertainty.

Score Card of Current Uncertainties on $(\Omega_{M}^{\mathrm{flat}}, \Omega_{\Lambda}^{\mathrm{flat}}) = (0.28, 0.72)$

Statistical

high-redshift SNe	0.05
low-redshift SNe	0.065
Total	***0.085***

Systematic

dust that reddens $R_B(z{=}0.5) < 2\ R_B(\mathrm{today})$	< 0.03
evolving grey dust	
clumpy	
same for each SN	
Malmquist bias difference	< 0.04
SN Ia evolution shifting distribution of prog mass/metallicity/C-O/..	
K-correction uncertainty including zero-points	< 0.025
Total identified entities/processes	***0.05***

Cross-Checks of sensitivity to

Width-Luminosity Relation	< 0.03
Non-SN Ia contamination	< 0.05
Galactic Extinction Model	< 0.04
Gravitational Lensing by clumped mass	< 0.06

Perlmutter *et al.* (1998)
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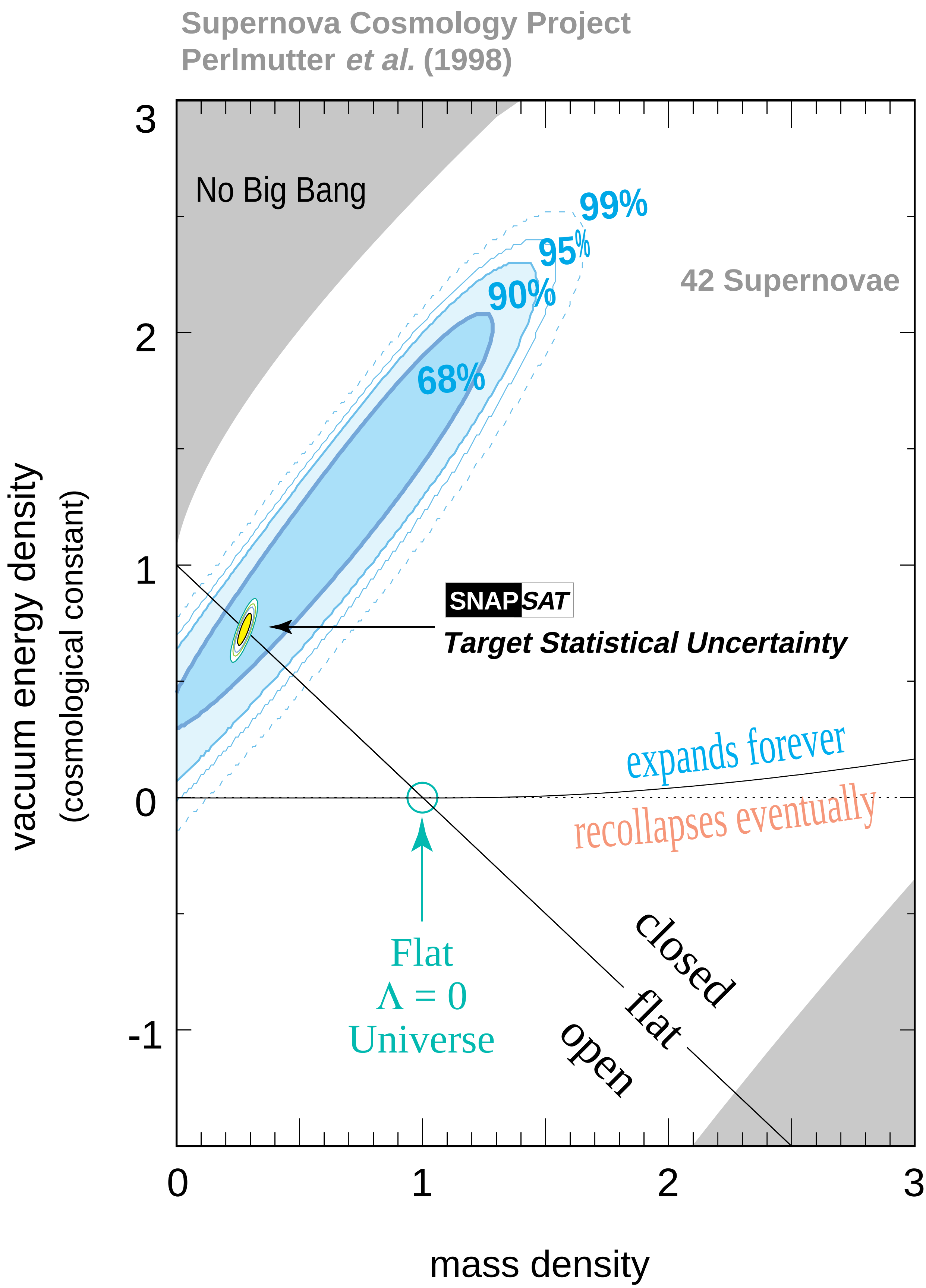

Supernova Cosmology Project
Perlmutter et al. (1998)
No Big Bang
99%
95%
90%
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42 Supernovae
SNAPSAT
Target Statistical Uncertainty
expands forever
recollapses eventually
Flat
Λ = 0
Universe
closed
flat
open
vacuum energy density
(cosmological constant)
mass density
3
2
1
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-1
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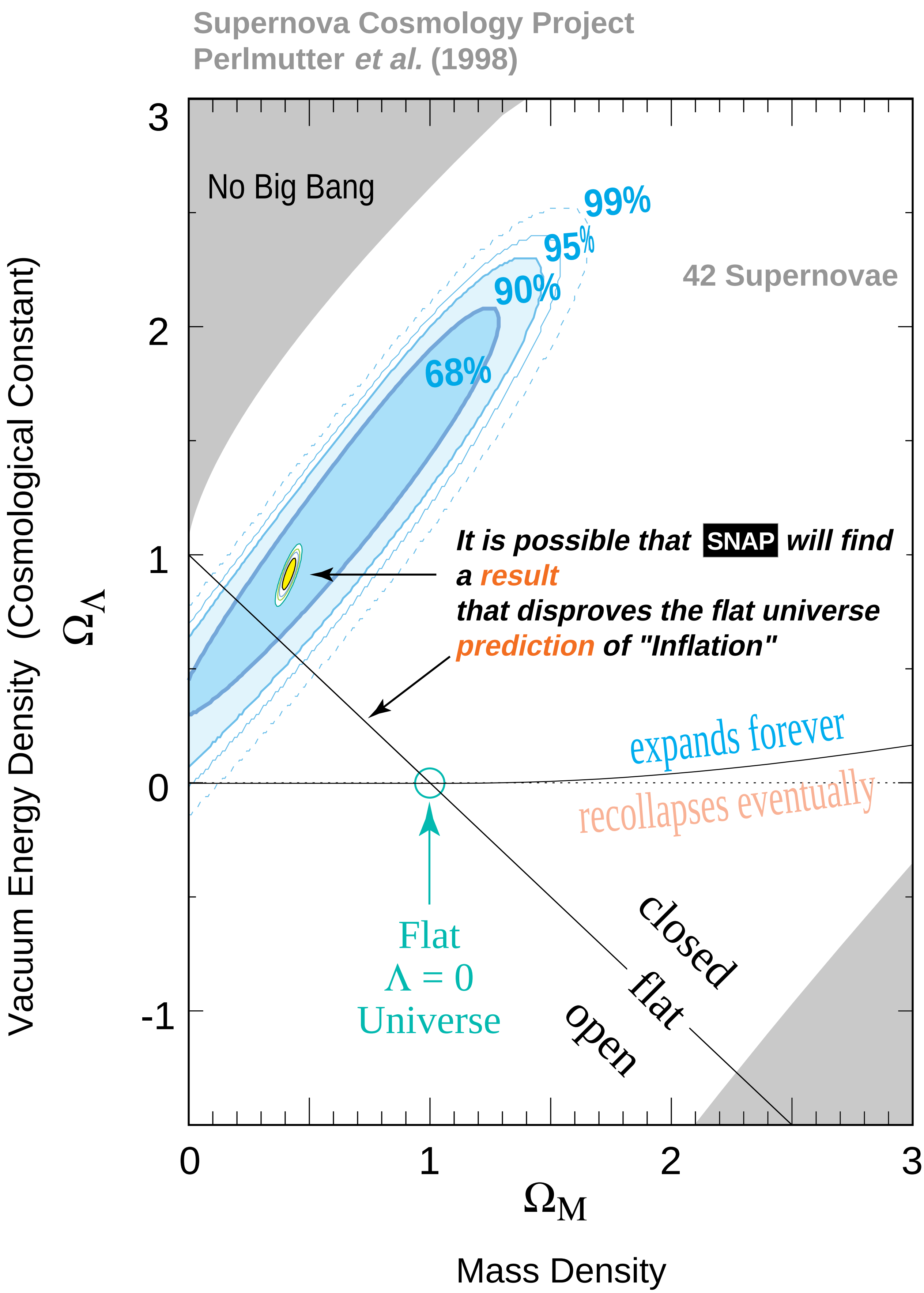
2
3



Supernova Cosmology Project
Perlmutter *et al.* (1998)
No Big Bang
99%
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42 Supernovae
It is possible that SNAP will find a result that disproves the flat universe prediction of "Inflation"
expands forever
recollapses eventually
Flat
$\Lambda = 0$
Universe
closed
flat
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Vacuum Energy Density (Cosmological Constant)
Ω_Λ
Ω_M
Mass Density
3
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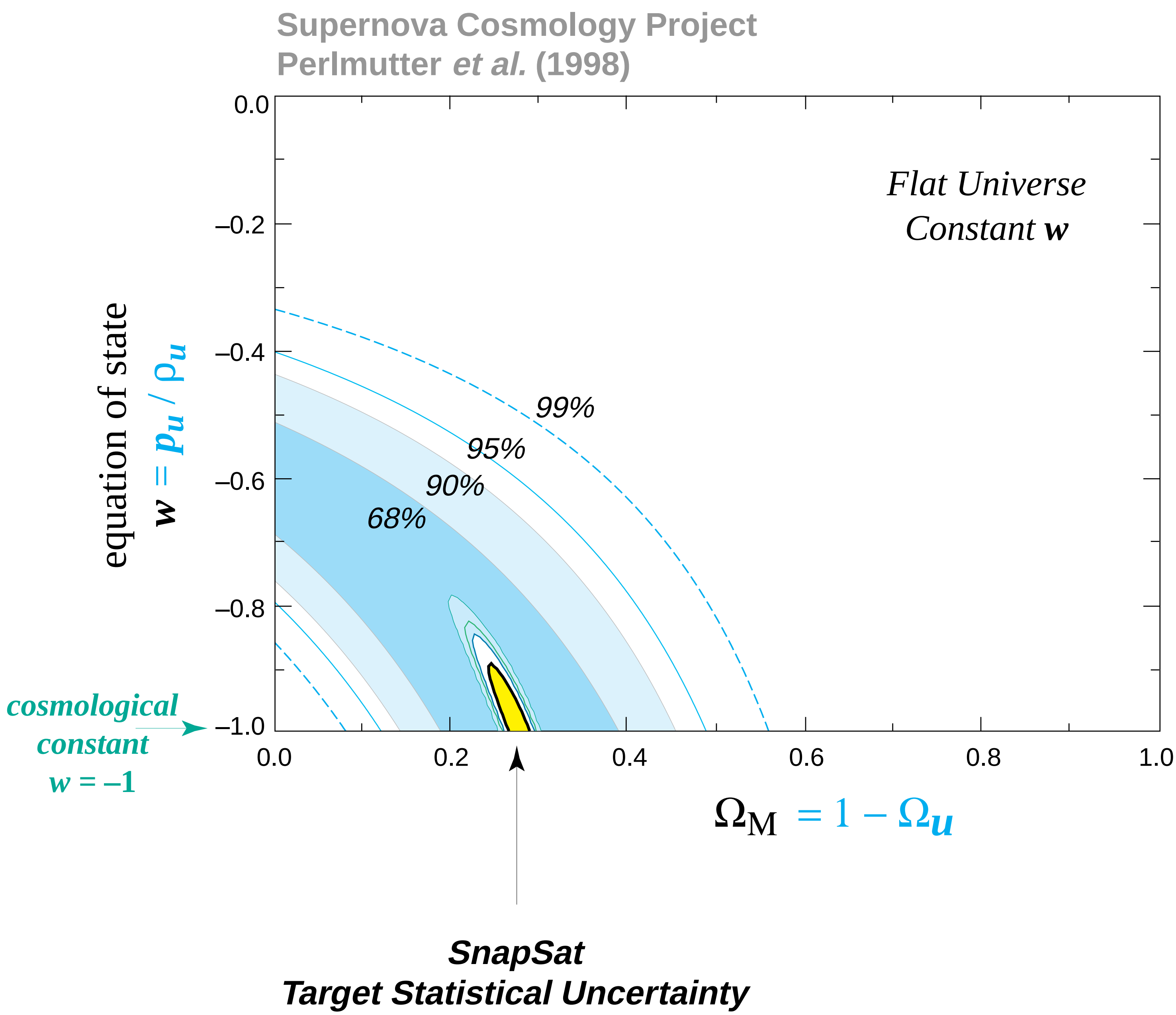
Dark Energy

Unknown Component, Ω_u, of Energy Density



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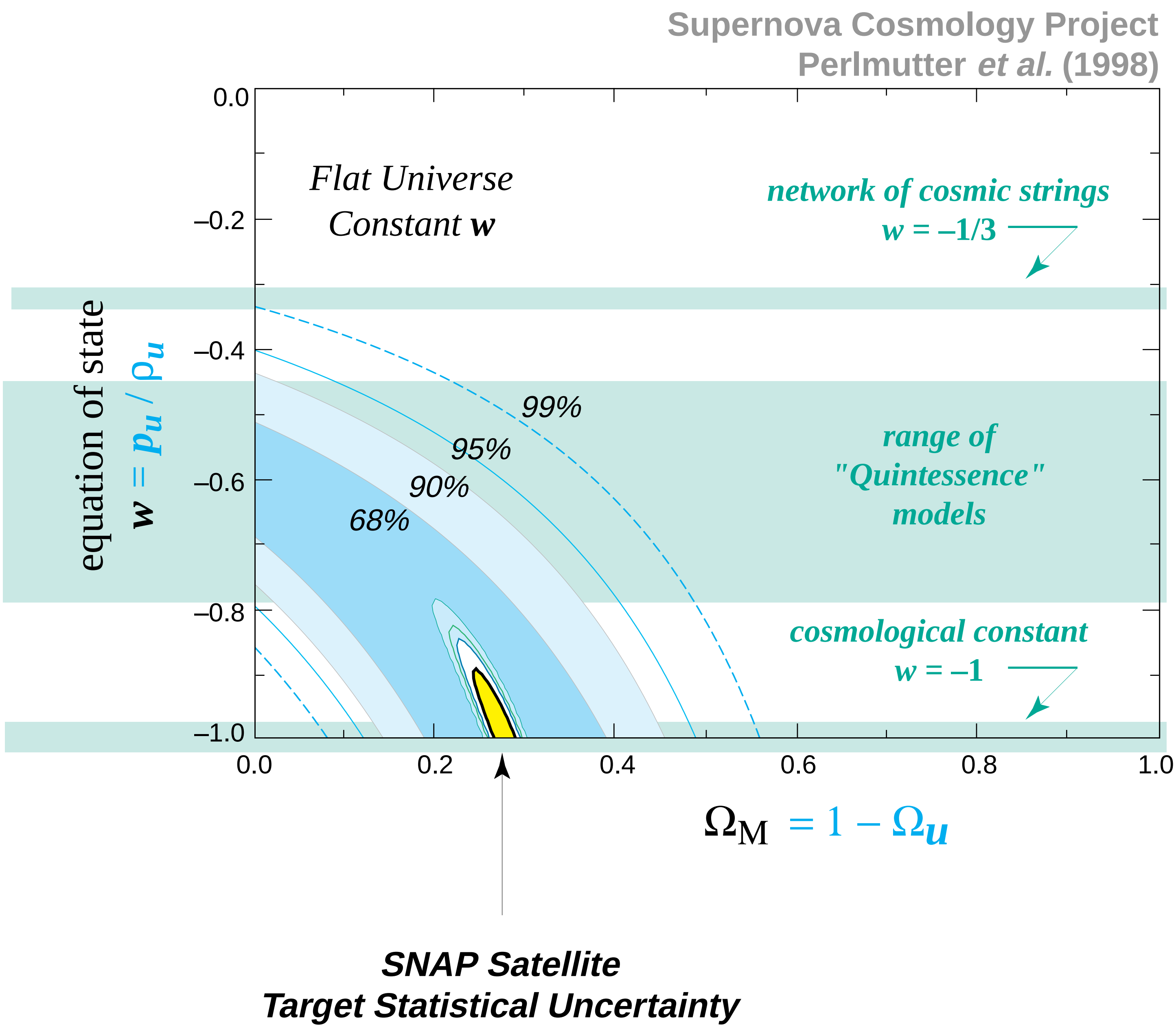
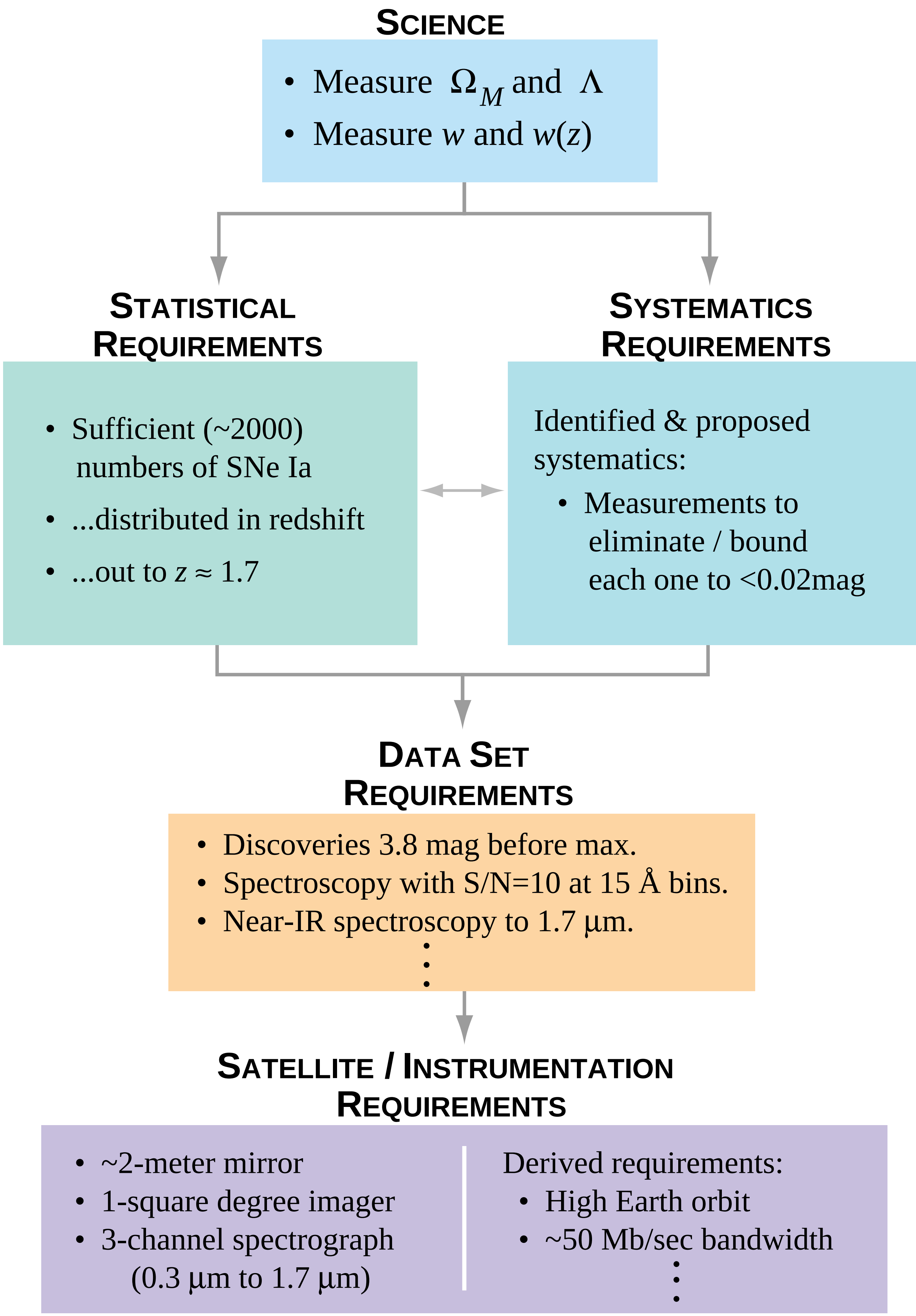
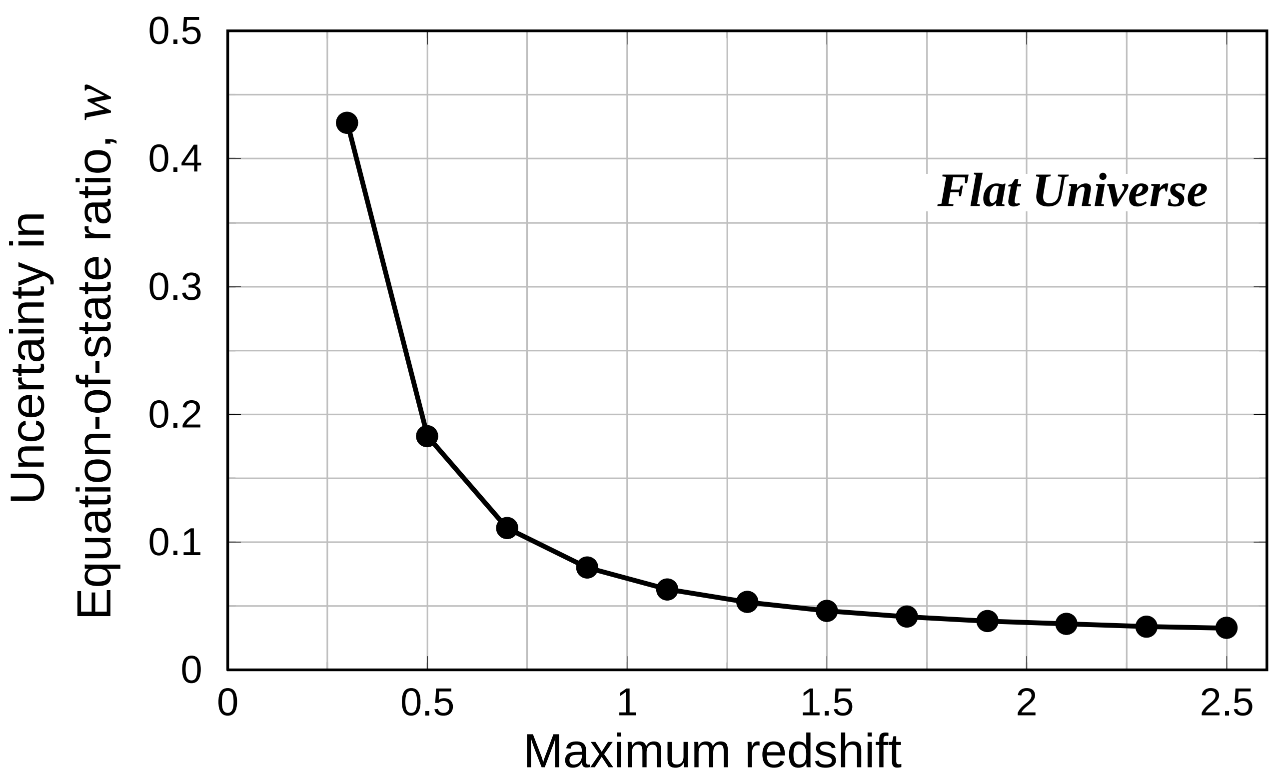
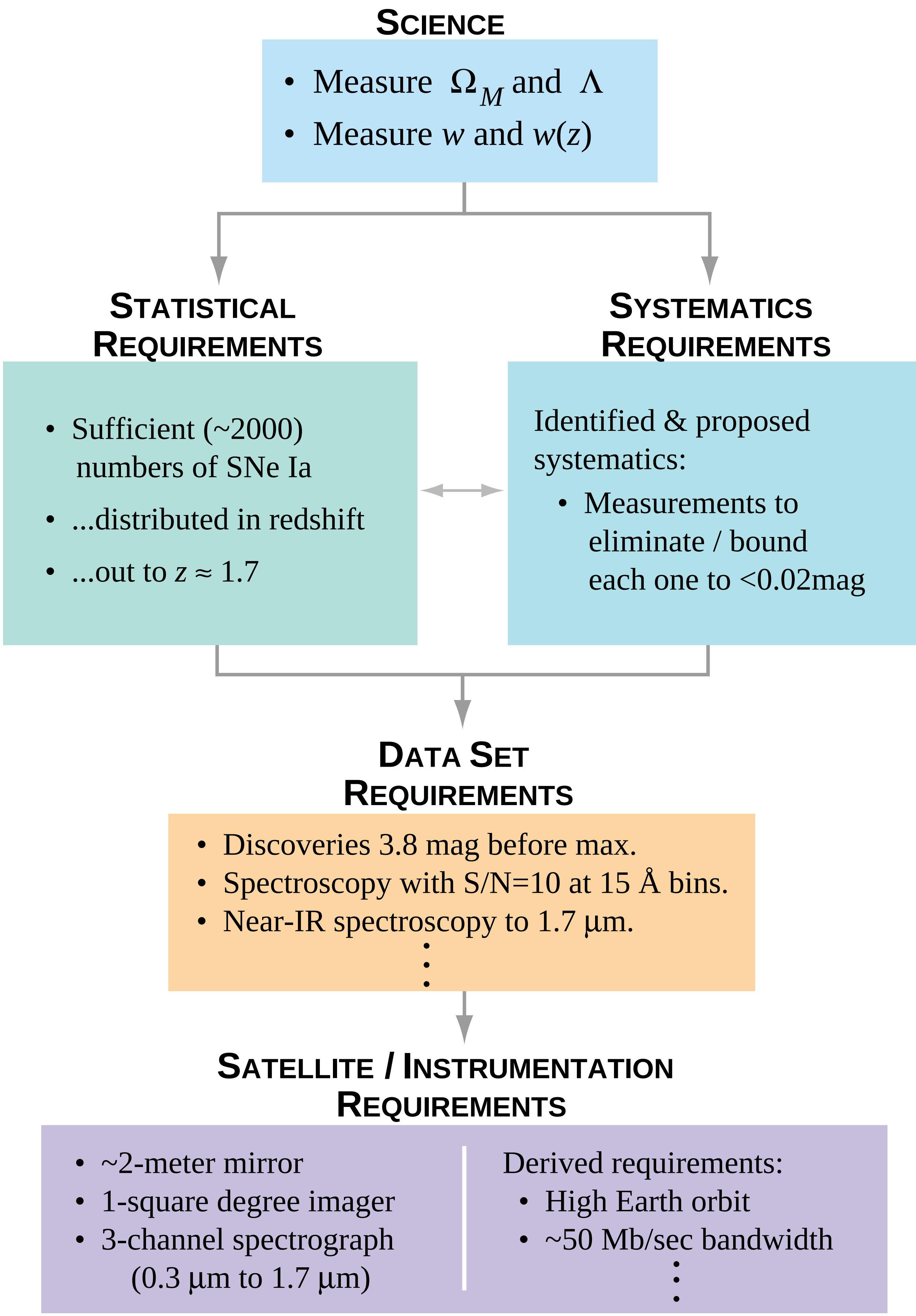



SCIENCE
• Measure Ω_M and Λ
• Measure w and $w(z)$
STATISTICAL REQUIREMENTS
• Sufficient (~2000) numbers of SNe Ia
• ...distributed in redshift
• ...out to $z \approx 1.7$
SYSTEMATICS REQUIREMENTS
Identified & proposed systematics:
• Measurements to eliminate / bound each one to <0.02mag
DATA SET REQUIREMENTS
• Discoveries 3.8 mag before max.
• Spectroscopy with S/N=10 at 15 Å bins.
• Near-IR spectroscopy to 1.7 μm.
SATELLITE / INSTRUMENTATION REQUIREMENTS
• ~2-meter mirror
• 1-square degree imager
• 3-channel spectrograph (0.3 μm to 1.7 μm)
Derived requirements:
• High Earth orbit
• ~50 Mb/sec bandwidth

How do uncertainties improve as we extend the range of redshifts?

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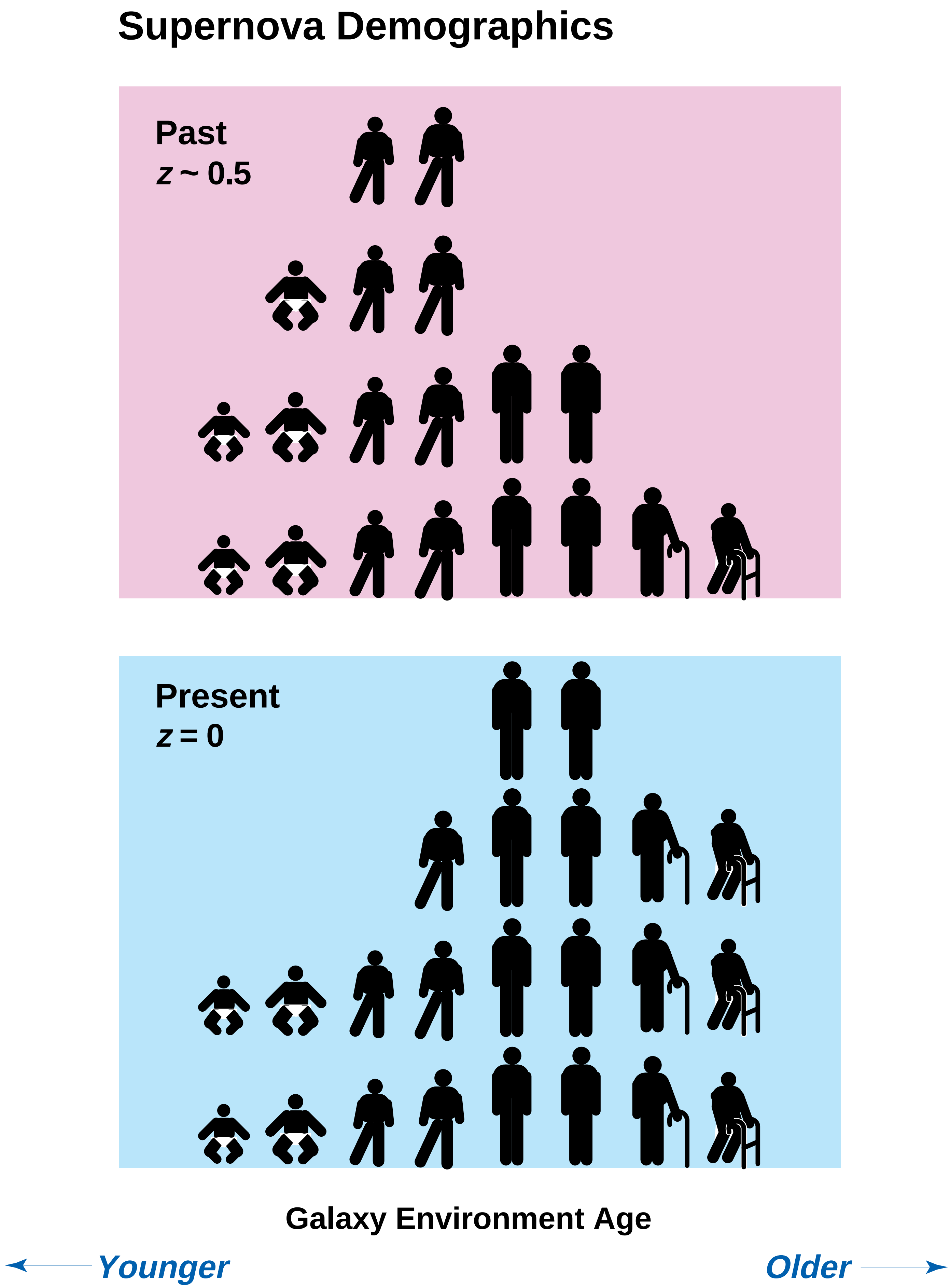
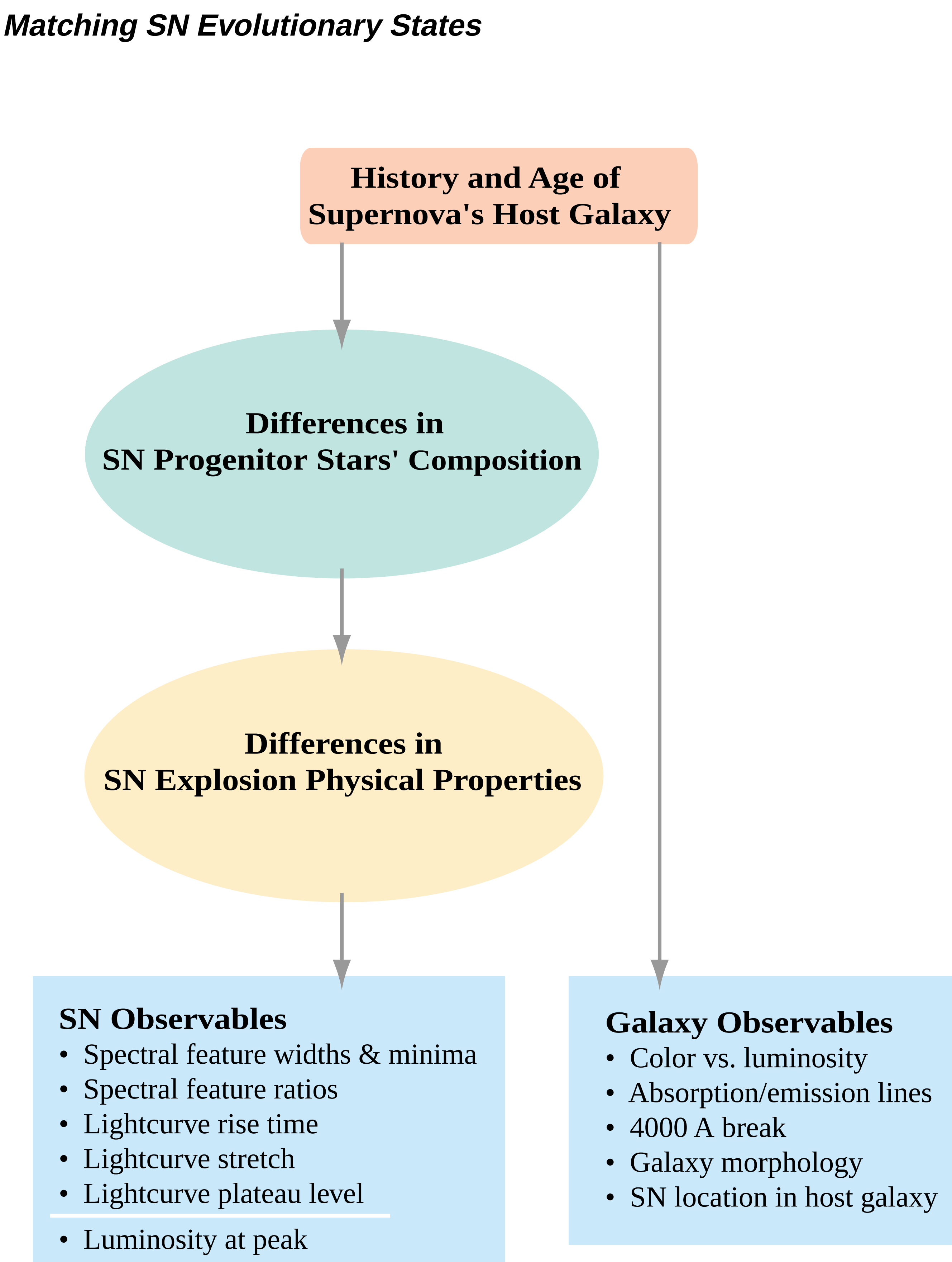
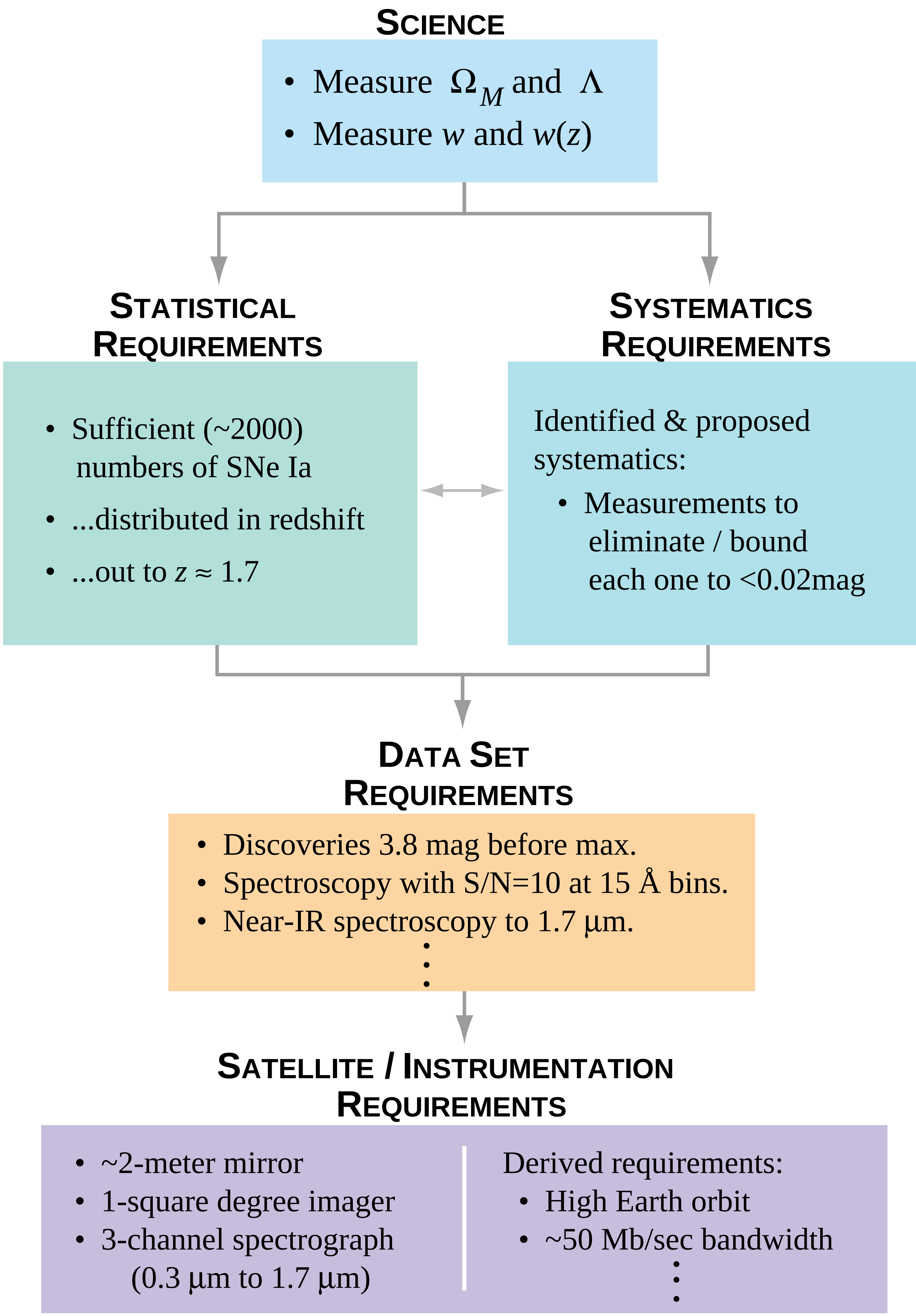

Supernova Demographics
Past
$z \sim 0.5$
Present
$z = 0$
Galaxy Environment Age
Younger
Older


Matching SN Evolutionary States
History and Age of Supernova's Host Galaxy
Differences in SN Progenitor Stars' Composition
Differences in SN Explosion Physical Properties
SN Observables
• Spectral feature widths & minima
• Spectral feature ratios
• Lightcurve rise time
• Lightcurve stretch
• Lightcurve plateau level
• Luminosity at peak
Galaxy Observables
• Color vs. luminosity
• Absorption/emission lines
• 4000 A break
• Galaxy morphology
• SN location in host galaxy



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SNAP Baseline Observing Strategy

Continuous monitoring (every 4 days) of

~2 sq. deg. to m_{AB} (1μm) ≈ 30

~20 sq. deg. to m_{AB} (1μm) ≈ 28.5

Discover *every* SN in these fields to m_{AB}^{limit}

Why a New Satellite?

Ground-based telescopes:

A dedicated 8-meter with 9-square-degree imager...

- cannot discover SNe within 2 restframe days of explosion beyond z = 0.6.
- cannot measure SN plateau level (>45 days after peak) beyond z = 0.7.
- even limiting redshifts to z = 0.6, can only discover fewer than 300 SNe/year.

Why a New Satellite?

Space-based (HST or NGST) telescopes:

NGST targets different and complementary science — higher redshifts ($z \gg 1$), fewer (~100) SNe and fewer observations (~4) per SN.

- NGST 16-square-arcminute field of view too small to efficiently find SNe in the target redshift range.

- Using NGST to obtain spectroscopy of the SN discovered by SNAP would be wasteful: Most of the time for over half a year would be spent slewing the NGST.

SNAP Complementary Science

Cosmological Parameters...

Type II supernova expanding photosphere
Weak lensing
Strong lensing statistics. Ω_Λ
Galaxy clustering, $P(k)$
z > 1 clusters and associated lensing
. . .

...and Beyond

GRB optical counterparts: rates, lightcurves, and spectra
MACHO optical counterparts by proper motion
Galaxy populations and morphology to co-added $m \approx 32$
Target selection for NGST
Kuiper belt objects
Supernova rates, star formation rates
Supernova phenomenology studies
Low surface brightness galaxies, luminosity function
. . .

NSF and NASA have well-established and well-known traditions in astrophysics and cosmology.

DOE also has a long history of astrophysics and cosmology contributions, but it is less well known:

Particle physics/cosmology theory:
Inflation, Quintessence, BBN...
Supernova cosmology measurements
Keck telescope
CMB studies
CCD technology
HEP large, complex detector experience
Supernova theory/simulations
Supercomputer centers / Grand challenges

We have an unusual opportunity
to answer fundamental questions of physics

Is the universe infinite?
Is space curved?
What is the fate of the universe?
What is the "Dark Energy" that is causing
the universe expansion to accelerate?

with a definitive, precision cosmology measurement.

The first complete calibrated supernova dataset,
2 orders of magnitude larger statistics (>2000 SNe),
extending much farther in distance and in time.
A ±0.03 measurement of the mass density.
A ±0.05 measurement of the vacuum energy density.
A ±0.06 measurement of the curvature.
A ±0.05 measurement of the Equation of State
of the "Dark Energy"